Circulatory System

Fish

Closed system

<u>single circuit</u>

heart → gills → body → heart

Special conditions for fish circulation

- **Environment is oxygen poor (1-8 ppm on average)**
- **Heart is simplest of vertebrates**
- **Fish have less blood volume than other vertebrates**

Special conditions for fish circulation

- **<u>Adaptations by fish</u>**

– Composition of blood (many different hemoglobins)

–polymorphism of hb-monomeric, oligomeric, different structures and number of alpha and beta chains, hb I – hb IV

Hb IV At low pH it displays oxygen release into the swim bladder and the retina. At pH 7.8, hemoglobin IV is totally oxygenated, while at pH 6.0, it is fully deoxygenated

Special conditions for fish circulation

- **Adaptations by fish**

– **Morphology of circulatory apparatus**

– **Behavioral responses to oxygen availability**

- **Temporal and spatial positions**
- **Aerial respiration or aquatic surface respiration**
- **Reducing activity**
- **Holding air bubble in mouth**

Functions of the Circulatory System

- **Delivers oxygen**
- **Delivers nutrients**
- **Removes metabolic waste**
- **Fights pathogens**

Components of the Circulatory System to Study

- **Blood**
  - **Erythrocytes-red cells**
  - **Leukocytes –white cells**
  - **Structure of Hemoglobin**

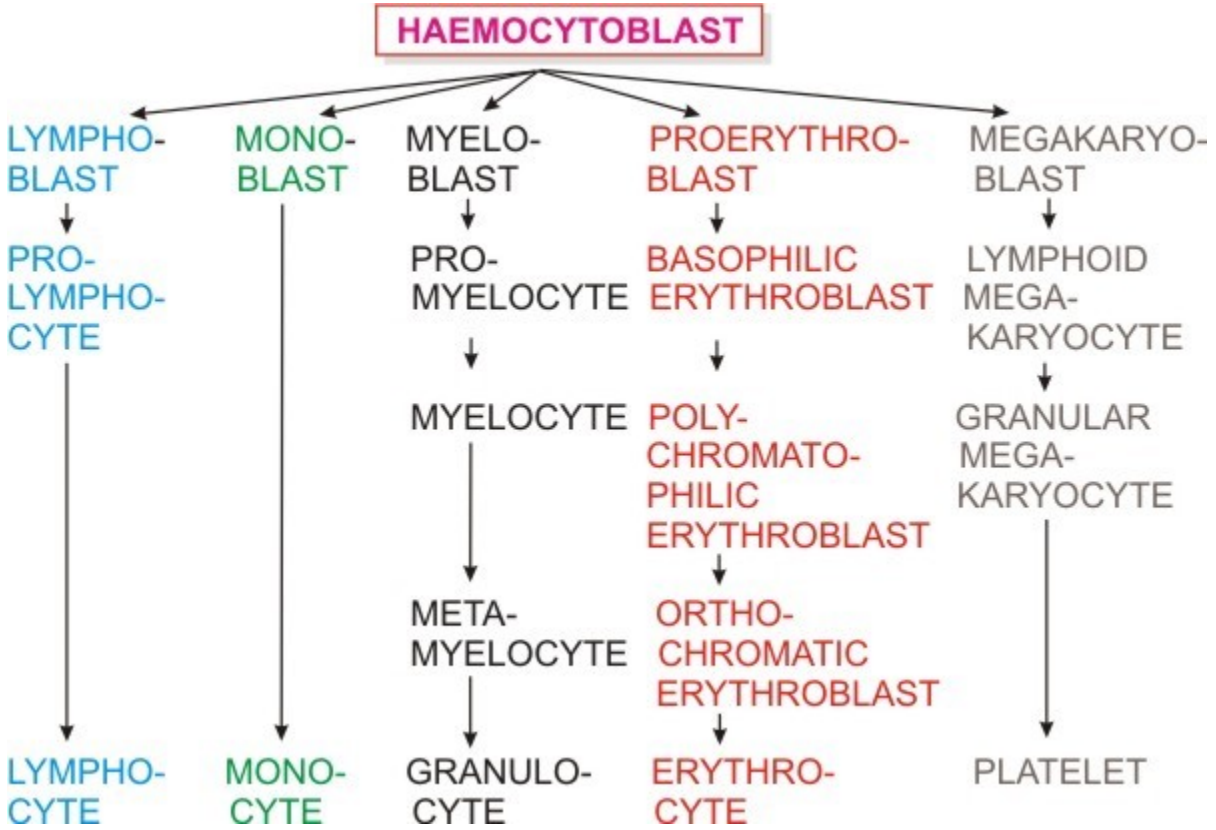
- **Vascular system**
  - **Heart**
  - **Vessels**

Formation of Fish Blood Cells

- **Formed from hemocytoblast**

(A blood cell derived from embryonic mesenchyme)

- **Blood forming site differs between fishes.**



Formation of Fish Blood Cells

– **Agnatha (jawless hagfish & lampreys)**

- **Mesodermal envelope around gut in hagfish**
- **Fatty tissue dorsal to nerve cord in lampreys**
  - **“fat column”**

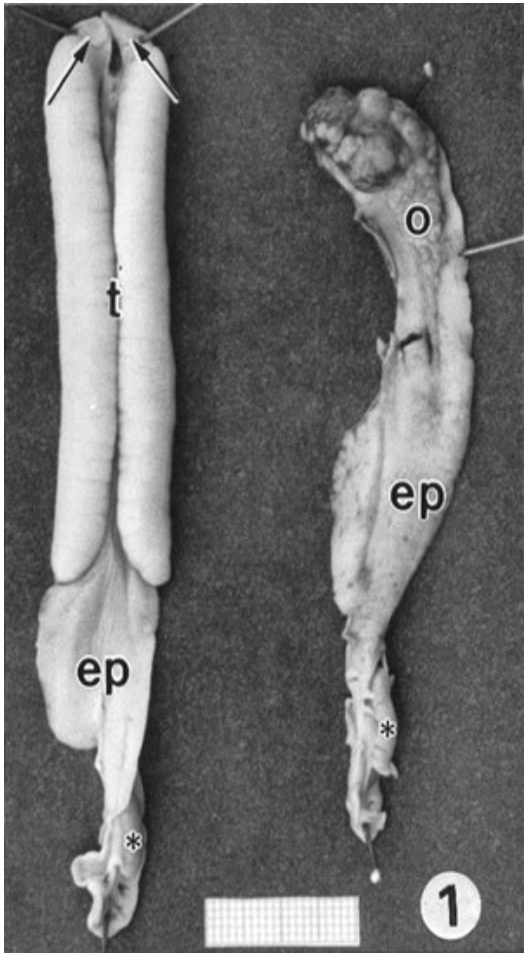
Formation of Fish Blood Cells

– **Elasmobranchs** **(cartilaginous fish sharks, rays & skates)**

- **Leydig organ (near esophagus)**

Along with the spleen and special tissue around the gonads

- **Epigonal organ (around gonads)**
- **Spleen**



Formation of Fish Blood Cells

- **Teleosts (bony fish)**

  – Kidney, Spleen, Cranium (cranial mesenchyme at embryonic stage)

- **Fish bone has no marrow**

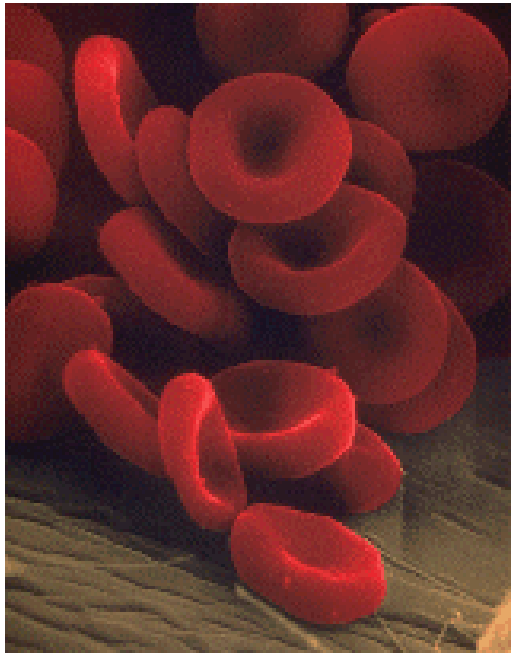
Components of Fish Circulatory Systems

- Blood:
  - aqueous solution
  - solutes (proteins, sugars, minerals)
  - blood cells
    - erythrocytes (red blood cells)
    - leucocytes (white blood cells)
      - lymphocytes
      - thrombocytes
      - monocytes
      - granulocytes

Blood Cells

- Leukocytes
- are numerous, ranging from 20 to 50 thousand,
- but some species have levels of up to
- 100,000/mm3

Erythrocytes-red cells



- **Most abundant fish blood cells**

(800 thousand to 3.5 million/mm3)

- **Nucleated**

- **Size range exists (elasmobranchs usually larger, but fewer)**

- **More active species have more red blood cells**

Hemoglobin of Fish Erythrocytes

- **Primary means for transporting oxygen**
  - **In some fish up to 15% may be in plasma**

- **A few fish have no hemoglobin (rare situation)**

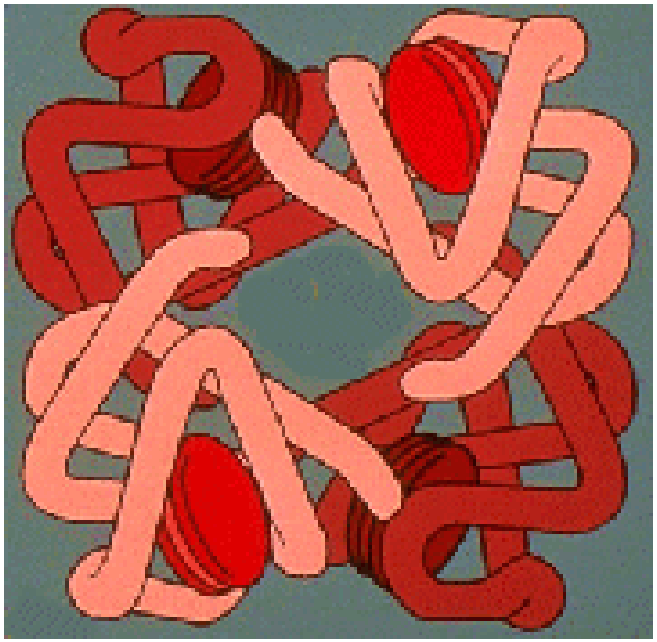
e.g. Channichthyidae in Antarctic waters

  - **Environmental oxygen high**
  - **Low metabolic requirements**
    - **very low temp, high O2 solubility, no RBC**

Oxygen carrying capacity of their blood is less than 10% that of their relatives with hemoglobin

Fish Hemoglobin Characteristics

- **Structure is different in different fish**
  - **Monomeric**
  - **Single-heme peptide molecules**
  - **Found in Agnatha**
- **Tetrameric**
  - **Four peptide chains**



Fish Hemoglobin Characteristics

- **May differ in many features**
  - **Composition of amino acids**
  - **Affinity for oxygen**
  - **Some salmonids have ~18 different kinds**

Having Different Hemoglobin Types

- **Different hemoglobins have different responses to:**
  - **temperature**
  - **oxygen absorption**
- **Allows fish to deal with changing conditions**
  - **Important for migratory species (salmon)**
- **Some fish gain or lose types as they age**

Blood Oxygen Affinity

- **pH**
  - **– Decreasing pH decreases affinity**
  - **– Often associated with carbon dioxide**

Root effect: increased proton or carbon dioxide concentration (lower pH) lowers hemoglobin's affinity and carrying capacity for oxygen

Blood Oxygen Affinity

Bohr Effect: **hemoglobin's oxygen binding affinity is inversely related both to acidity and to the concentration of carbon dioxide**

- **Increase in CO_2 drives off O_2**
- **Decrease in blood pH magnifies Bohr effect**

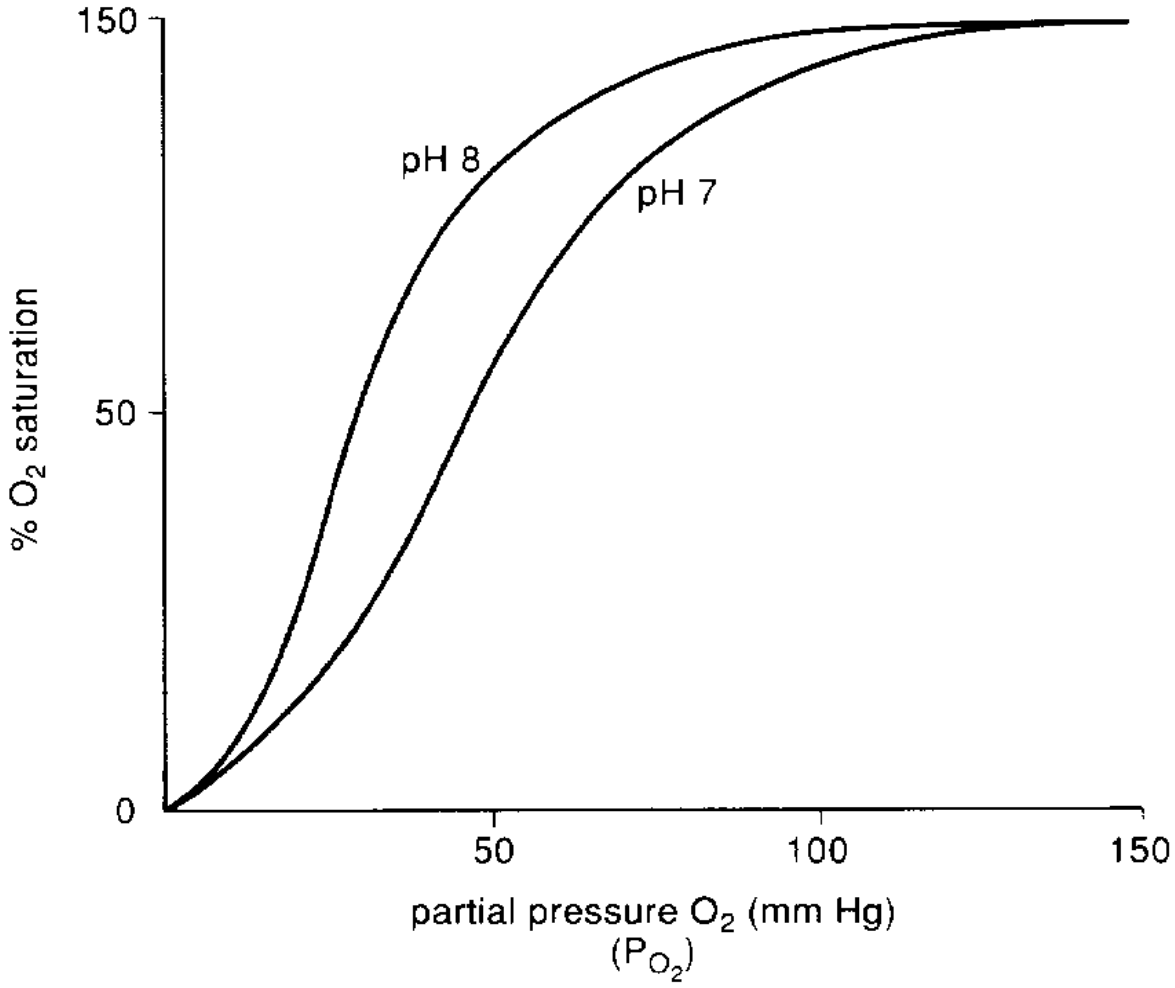


FIGURE 23–3 Effect of blood pH on oxygen dissociation curve. At a selected partial pressure of oxygen, the percent saturation will be much lower at pH 7 than at pH 8 (Bohr effect).

Blood Oxygen Affinity

- **Temperature**
  - **Increase in temperature depresses oxygen affinity and capacity (total amount bound)**
  - **Results in fish having narrow temperature tolerances**

Fish Circulatory System

- **Primary circulation**
  - **Closed system**
    - **Heart**
    - **Arteries**
    - **Capillaries**
    - **Veins**
- **Secondary circulation**
    - **Collects blood that is outside the primary**
    - **Originally thought to be lymphatic**
- **No lymph or lymph nodes.**

Chambers of the Fish Heart

(1) Sinus venous

- **Collects blood from venous ducts**

(2) Atrium

- **Accelerates blood flow**

(3) Ventricle

- **Large muscled chamber**
- **Provides propulsive flow for circulation**

(4) Bulbus arteriosus (bony)

Conus arteriosus

- **Changes blood from a pulse to continuous flow**

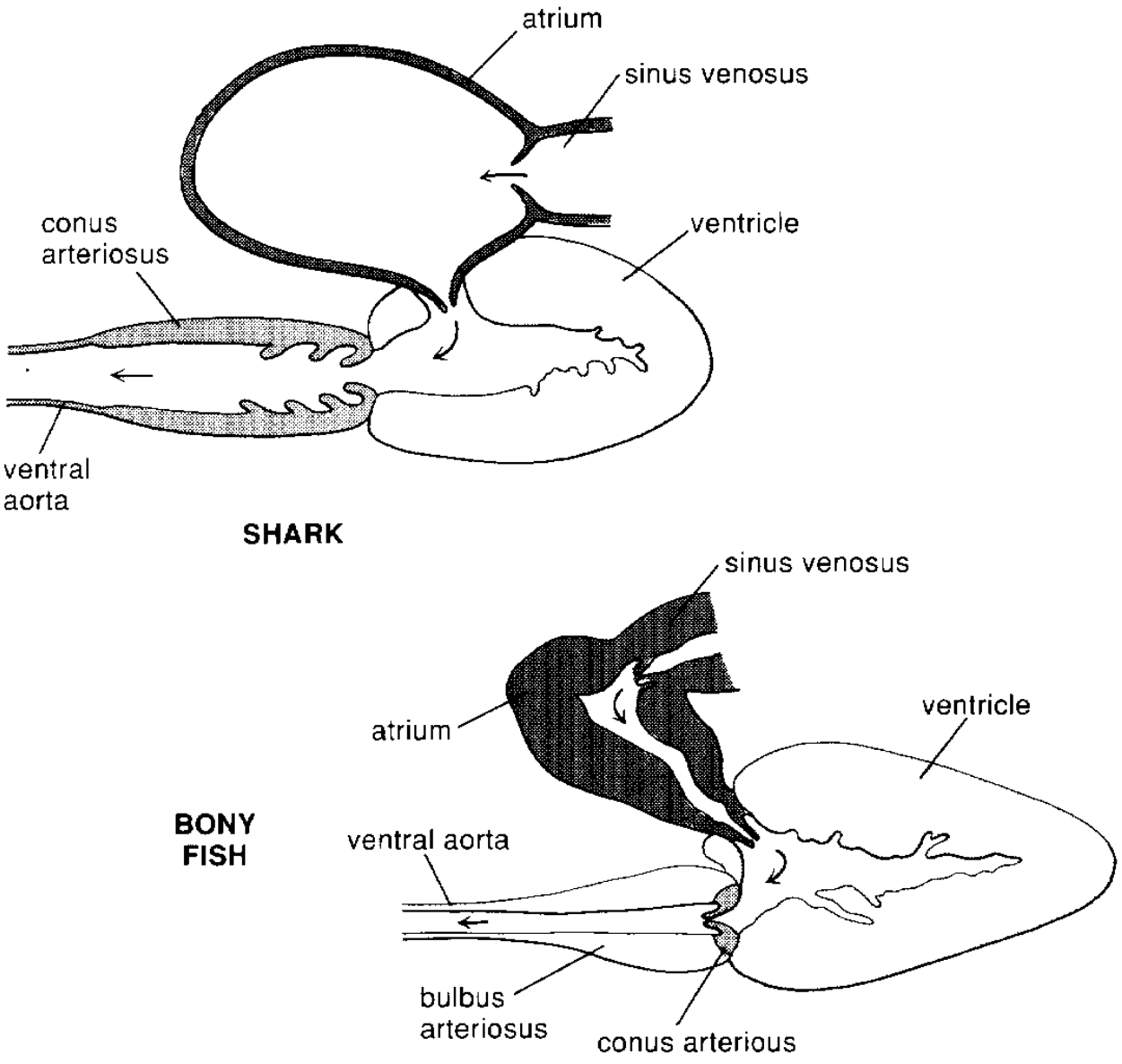
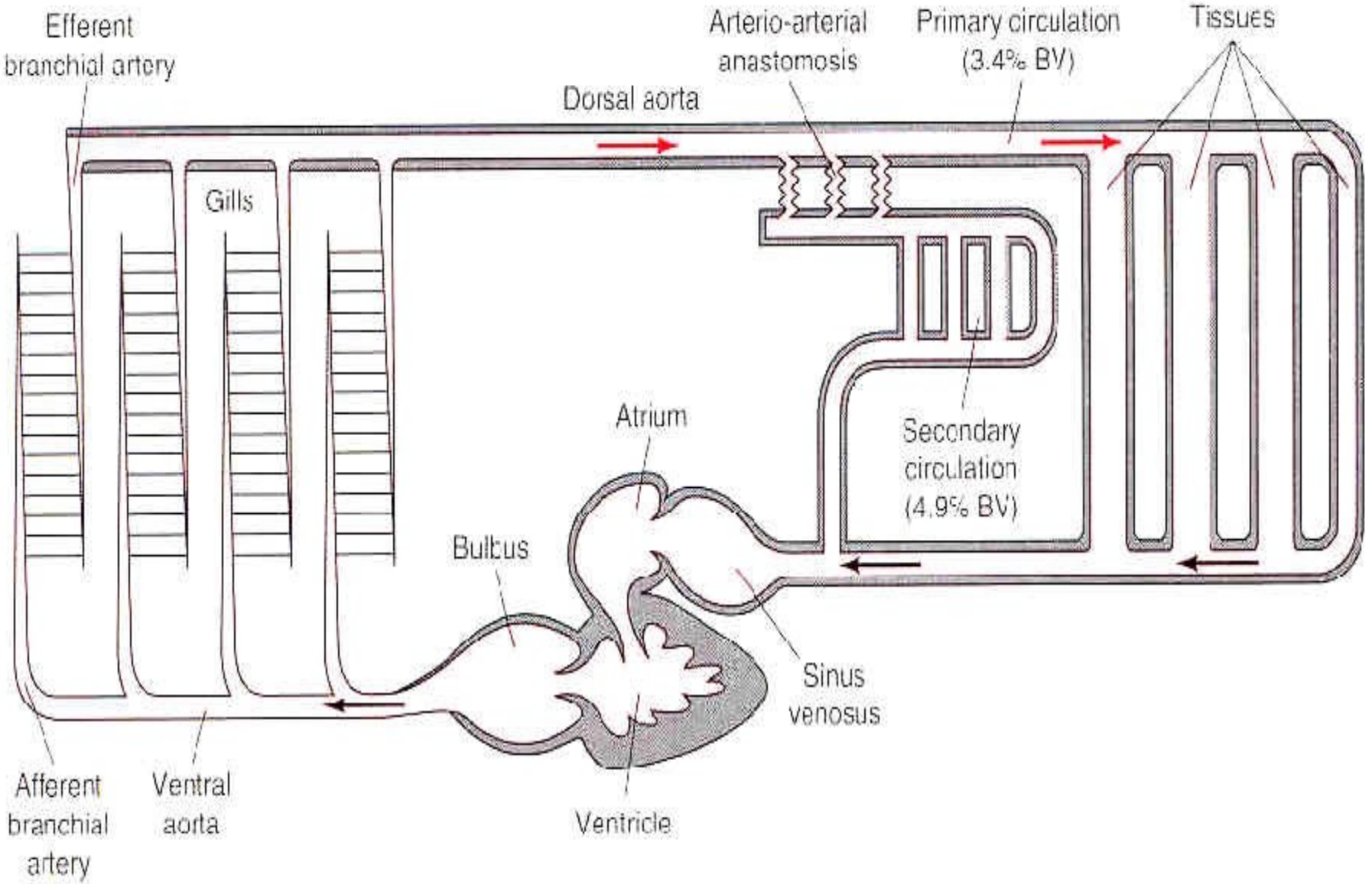


FIGURE 23–1 Diagrams of heart in shark and bony fish.


Efferent branchial artery
Arterio-arterial anastomosis
Primary circulation (3.4% BV)
Tissues
Dorsal aorta
Gills
Atrium
Secondary circulation (4.9% BV)
Bulbus
Sinus venosus
Afferent branchial artery
Ventral aorta
Ventricle

Divisions of Primary Circulation

- **Branchial circulation**
  - **– Blood from heart through gills**

- **Systemic circulation**
  - **– Blood from gills to body to heart**

- **Blood flow is continuous from heart, to lungs, to body, back to heart**

Proximity of Heart & Gills

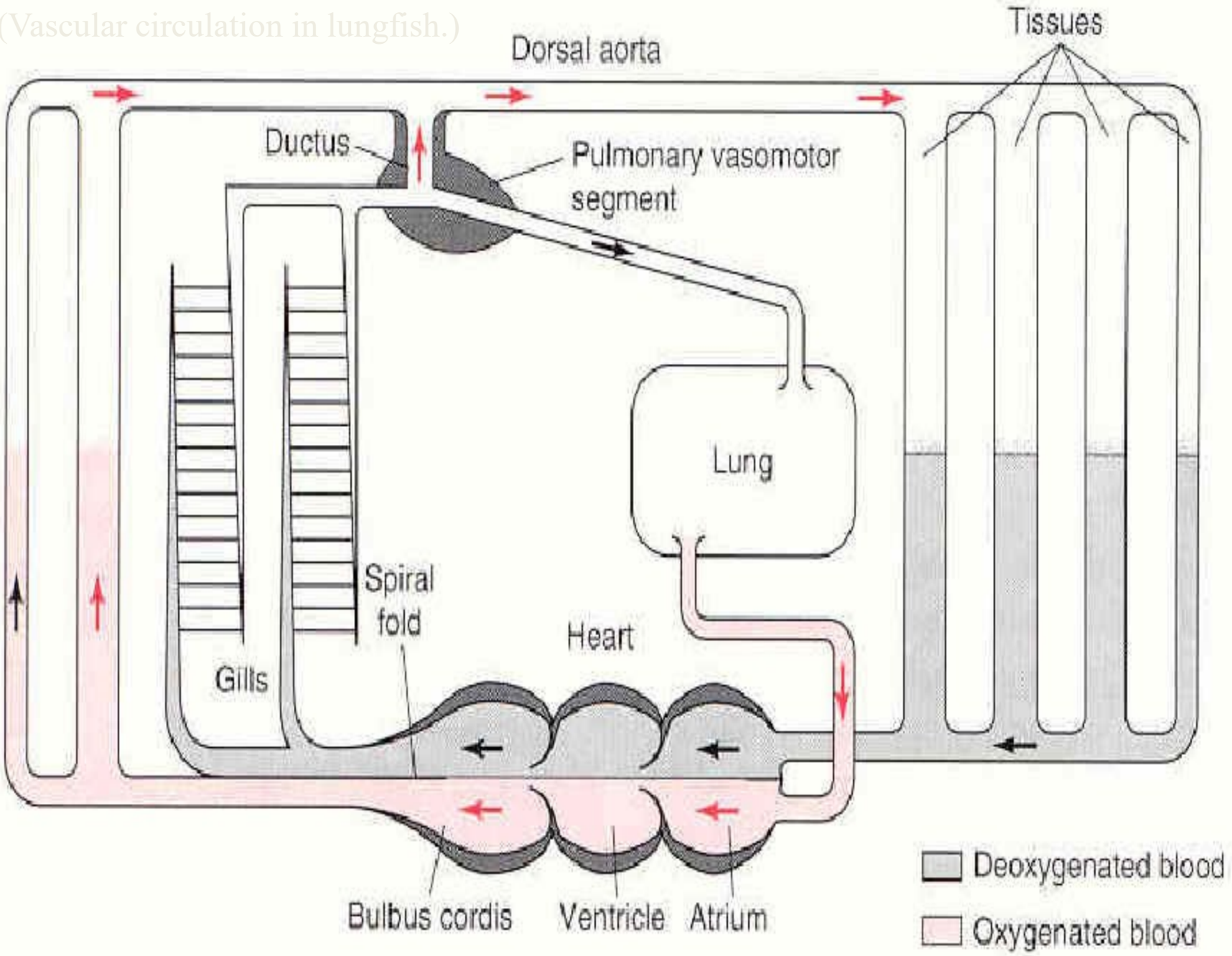
Exceptions to Normal Circulation

- Hagfish have accessory inline hearts
- Lungfish have pulmonary circulation
- There are also many small adaptations in some species.

Structure of the Fish Heart

- **Four chambered heart**
- **All four chambers are in line**
- **The heart pumps only venous blood**
- **Except for a few air breathing fish, all blood is pumped to the gills**

(Vascular circulation in lungfish.)



Conus vs. Bulbus Arteriosus

- **Conus Arteriosus**
  - **Contractile**
  - **Cardiac muscle**
  - **More than one valve**

- **Bulbus Arteriosus**
  - **Elastic**
  - **Mostly connective tissue**
  - **One valve dividing it from ventricle**

The Hagfish Heart

- **Most primitive**
- **Sinus venous well developed**
  - **Divided into two parts to receive different veins**
- **Bulbus arteriosus**
- **Have 3 additional hearts**
  - **Cardinal heart in head**
  - **Caudal heart near end of tail**
  - **Portal heart – pumps blood through liver**

Lamprey Heart

- **Largest of fish hearts**
- **Atrium overlies ventricle**
- **Bulbus arteriosus**

Elasmobranch Heart

- **Conus arteriosus**
- **Sinus venosus with almost no cardiac muscle**
- **Ventricle has two muscle layers**
  - **Compacta = compact outer layer**
  - **Spongiosa = inner layer**

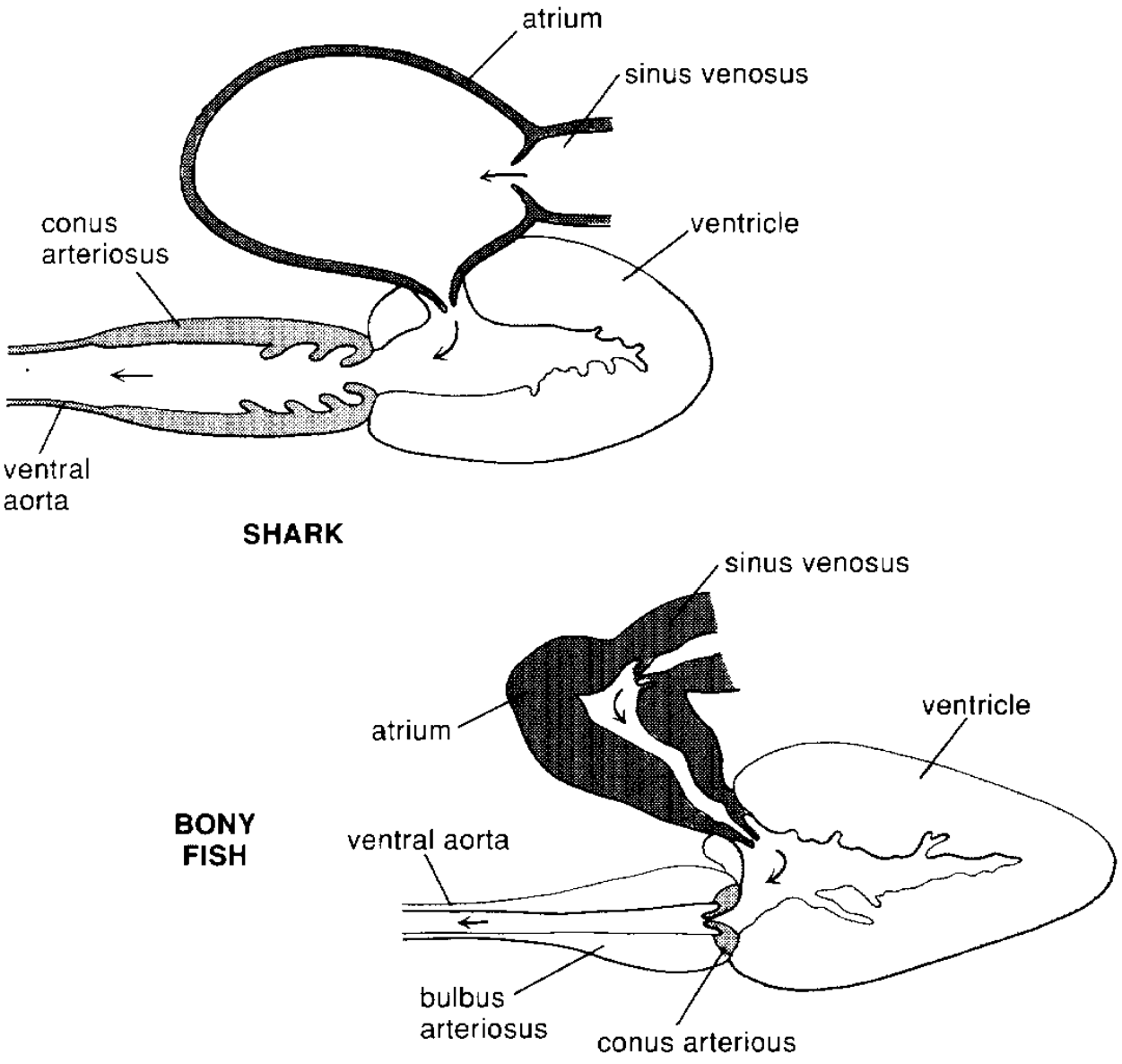


FIGURE 23–1 Diagrams of heart in shark and bony fish.

Teleost Heart

- **Variation exists across the group**
- **Sinus venosus is thick-walled**
- **Most have bulbus arteriosus**
- **Some have conus arteriosus (usually more primitive)**

Lungfish Heart

- **Atrium is divided into two parts by an incomplete septum**
  - **Functional 3 chamber heart**
  - **Like amphibians**
  - **Right atrium larger than left**
  - **Right = deoxygenated from sinus venosus**
  - **Left = oxygenated from pulmonary vein**